Zeebrugge Model

3D wave run-up measurements and analysis

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THROUGH PROTOTYPE
MONITORING AND MODELLING

OPTICREST

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Zeebrugge model: 3D wave run-up measurements and analysis

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REPORT

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1 Introduction

This report presents the model test results on wave run-up and run-down on the Zeebrugge breakwater under short-crested oblique wave attacks. The model test was performed in March-April 2000 at the Hydraulics & Coastal Engineering Laboratory, Aalborg University.

2 Model set-up

The tests have been carried out at the Hydraulics & Coastal Engineering Laboratory at Aalborg University. The model is constructed in the 3D shallow water basin. The basin is 12 by 18 meters. The wave maker allows for water depths up till approximately 60cm water depth. The wave maker has 25 paddles, each 50cm wide. The paddles are hinged at the moving arms in such a way that the paddle fronts gives a "snakelike" movement when generation 3D waves or oblique waves. A photo of the wave basin can be seen in figure 1.

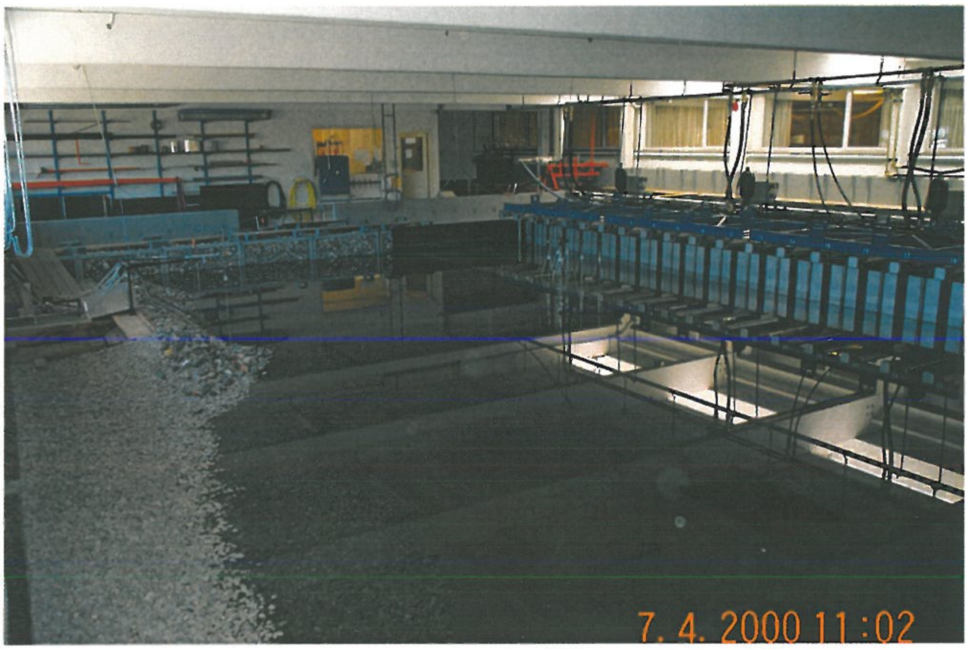


Figure 1. Photo showing 3D wave basin.

The model length scale is 1:40. The model has been used for 2D wave tests, see Schlütter et al. (1999), where a detailed description of the model can be found.

The short-crested wave in the basin is recorded by a group of 7 wave gauges at the location of the wave rider 2, cf. Figure 2.

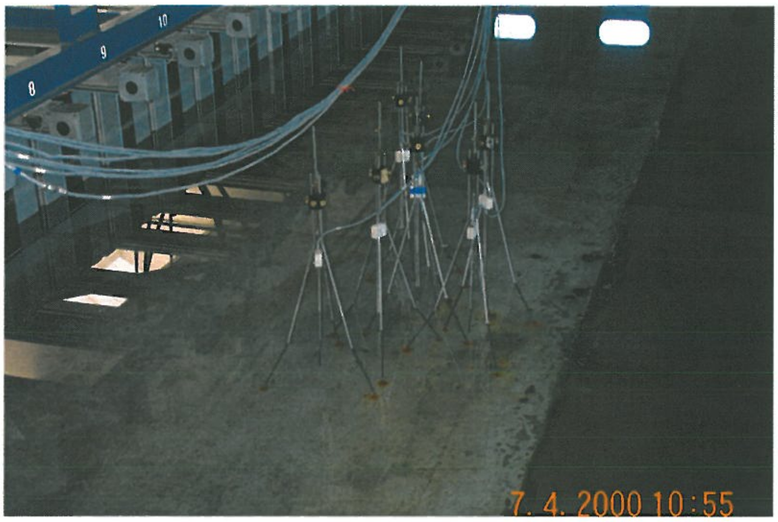


Figure 2. Photo showing the wave gauges at the location of the wave rider 2.

The wave run-up and run-down are recorded by both the wave gauge and the step gauge, The ends of the needles of the step gauge follow the armour slope with a distance of 2mm, while the wave gauge is approximately 5mm away from the armour slope, cf. Figure 3.

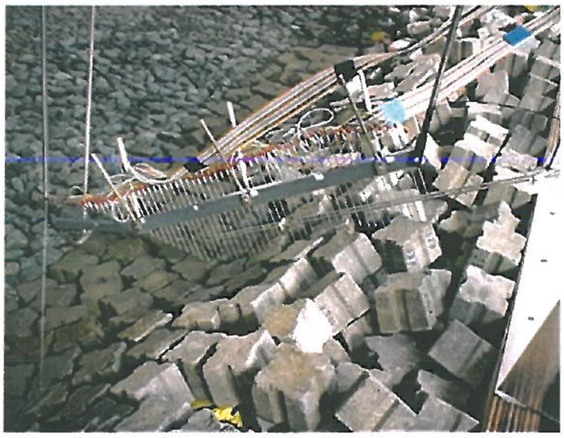


Figure 3. Photo showing the wave gauge and step gauge for run-up measurement. The wave gauge is approximately 5 mm away from the armour slope while the step gauge is 2 mm away.

The original specified prototype wave climate are: H_s=5m, T_p=9s and water level +3m. Because the experience from AAU and FC reveal that such a wave breaks often in the foreshore, the wave height is modified to H_s=4m. This leads to the wave climate in the model: H_s=0.1m, T_p=1.42s and h=0.41m at the wave paddle.

During the tests, wave overtopping events occur sometimes, with a very limited amount of water. Therefore, no results on wave overtopping is given in the report.

Each test series has a duration of 2000 seconds corresponding to app. 1500 individual waves. The test and analysis follow strictly the report: "Laboratory Investigations – Methodology" (final version, June 1999) subtask 3.1.

3 Wave analysis

Wave generation is carried out using the PROFWACO wave generation software (AAU, 1993). The program generates steering signals to the 25 servo controllers controlling the hydraulic motors. The wave maker is described in detail by Frigaard (1993). Figure 4 shows the generated waves in the wave basin.

a) Mean incident angle: 0^0
Energy spreading angle: 0^0

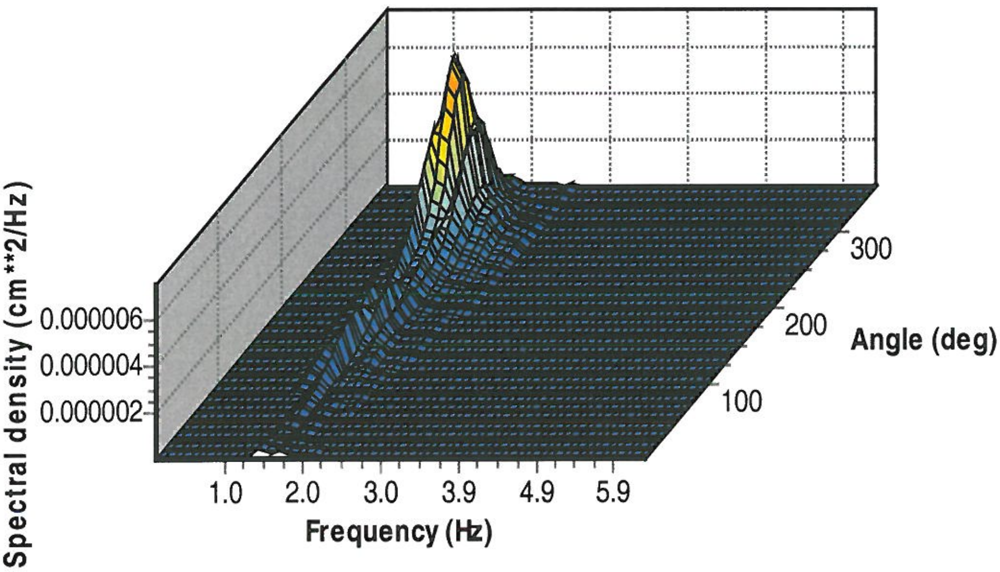
b) Mean incident angle: 0^0
Energy spreading angle: 30^0

c) Mean incident angle: 20^0
Energy spreading angle: 0^0

d) Mean incident angle: 45^0
Energy spreading angle: 0^0

Figure 4. Photo showing the short-crested waves in the wave basin.

The elevation signals recorded by the group of 7 waves gauges are analyzed by a directional estimation method using a Bayesian approach, which separates the recorded signals into the incident and reflected energy spectra under various wave frequencies and wave angles. An example is given in Figure 5.



	Hs (m)	*Tp (s)*	*Wave angle (head-on=270^0)*	*Energy spreading angle*
Incident	0.1	1.45	284^0	33^0
Reflected	0.04	1.45	123^0	35^0

Figure 5: Wavelet after the Bayersian directional spectrum reflection analysis.

For the long-crested waves reflection analysis is performed by the Mansard and Funke method (Mansard et al. 1980). Figure 6 shows the separated incident and reflected energy spectra.

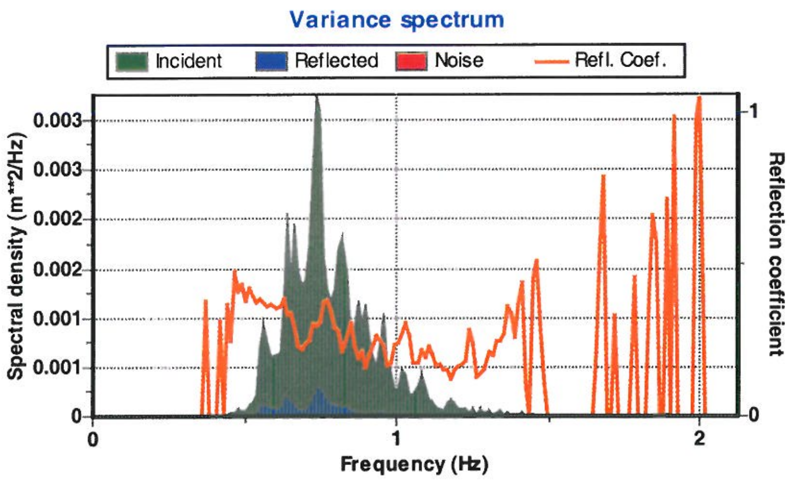


Figure 6. Incident and reflected energy spectra of long-crested waves.

4 Wave run-up and run-down analysis

As mentioned before, wave run-up and run-down are measured by the wave gauge and the step gauge. Because the step gauge is placed closer to the armour slope than the wave gauge, and the wave up-rush and down-rush are formed of a thin layer of water, it can be expected that the step gauge will give a high wave run-up and lower wave run-down.

The step gauge has two output channels, one is telling how many needles are wet (sum), while the other is telling the highest wet needle (maximum). Due to the water spray caused by wave up-rush and down-rush, the Maximum will predict a higher run-up and lower run-down than the sum.

A recorded time series by the wave gauge, the step gauge maximum and the step gauge sum is given in Figure 7.

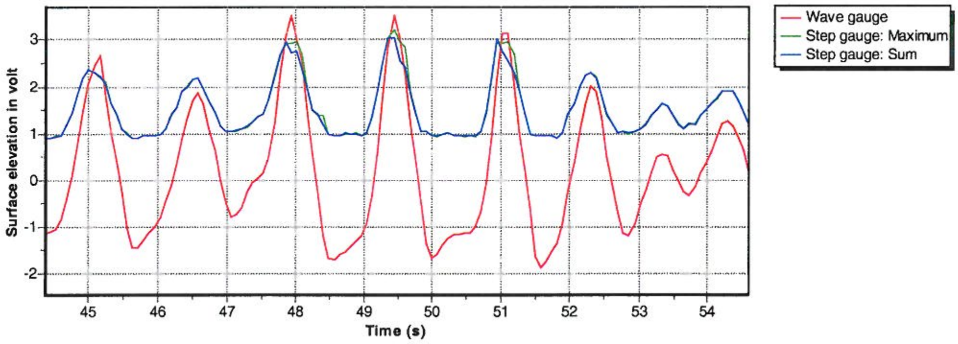


Figure 7. A time-series measured by wave gauge and the step gauge.

It seems that the run-down measurement of the step gauge has been cut-off. But the careful visual observation of run-down phenomenon reveals that, during the down-rush event, water is running out from the holes between the antifer cubes. This water out-rush has a very thin layer, which can be detected by the step gauge, but not the wave gauge. The down-rush lasts until the next run-up event occurs, which leads to the time series of the step gauge recording seems to be cut-off, cf. Figure 8.

Figure 8. Out-rush from holes between antifer cubes during a down-rush event.

An example of the distribution of wave run-up and run-down recorded by the wave gauge, the step gauge maximum and the step gauge sum is given in Figure 8.

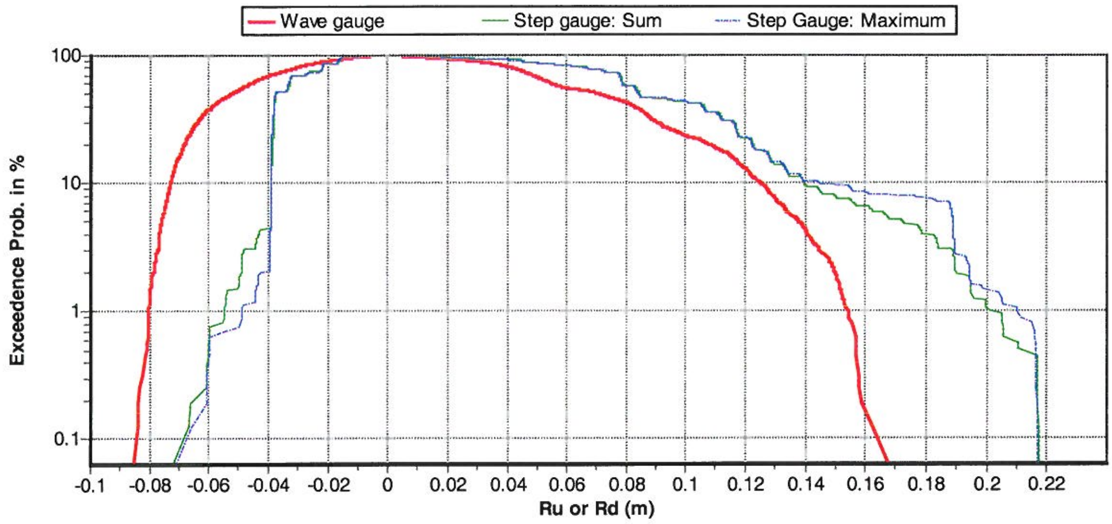


Figure 8. An example of the wave run-up and run-down distribution measured by wave gauge and the step gauge.

With respect to Ru,2%, the value from the step gauge is in general 30% higher than the wave gauge. And $R_{d,2\%}$ predicted by the step gauge is 30% lower than that by the wave gauge.

5 Test performed and results

Table 1 gives a summary of tests performed and results. In the table the run-up and run-down are those measured by the step gauge sum. For all the test series, the peak wave period is very close to the target value 1.42 s.

It can be seen from the table that while wave heights and wave periods are close to the target values, it is difficult to control the wave mean incident angle and energy spreading angle. The number of performed tests is twice as many as planned in order to cover the target values.

Test	Incident Hs (m)	Mean incident Angle (deg)	Energy spreading angle (deg)	Ru,2% (m)	Rd,2% (m)
Z051a	0.1	0	12	0.188	0.048
Z051a-1	0.095	0	0	0.193	0.040
Z051a-2	0.095	0	0	0.193	0.040
Z051	0.1	0	0	0.190	0.049
Z051-3	0.106	4	34	0.197	0.045
Z052	0.105	6	39	0.161	0.039
Z053-1	0.103	23	12	0.189	0.050
Z053-2	0.099	23	11	0.167	0.044
Z054	0.099	24	13	0.163	0.049
Z055-1	0.094	10	38	0.144	0.065
Z055-2	0.096	9	39	0.150	0.039
Z055-3	0.102	7	35	0.197	0.053
Z055-4	0.105	12	32	0.198	0.078
Z056-2	0.099	23	12	0.165	0.060
Z057-1	0.10	14	33	0.183	0.044
Z057-2	0.101	36	14	0.140	0.039
Z057-3	0.099	18	20	0.192	0.049
Z058-1	0.098	9	37	0.156	0.078
Z058-2	0.103	15	32	0.193	0.039
Z058-3	0.102	18	30	0.193	0.078
Z059-2	0.108	35	14	0.125	0.039
Z060-1	0.103	17	29	0.185	0.038
Z060-2	0.101	24	24	0.173	0.038
Z061-1	0.097	21	27	0.179	0.038
Z061-2	0.099	18	29	0.188	0.039
Z062-1	0.098	45	16	0.129	0.045
Z063-1	0.096	48	22	0.119	0.045

Table 7: Tests performed and analysis results.

6 Influence of wave energy spreading angle and wave incident angle on run-up

Figure 9, showing $R_{u,2\%}/H_s$ of the head-on waves with various energy spreading angles, reveals that the energy spreading angle has insignificant influence on the wave run-up.

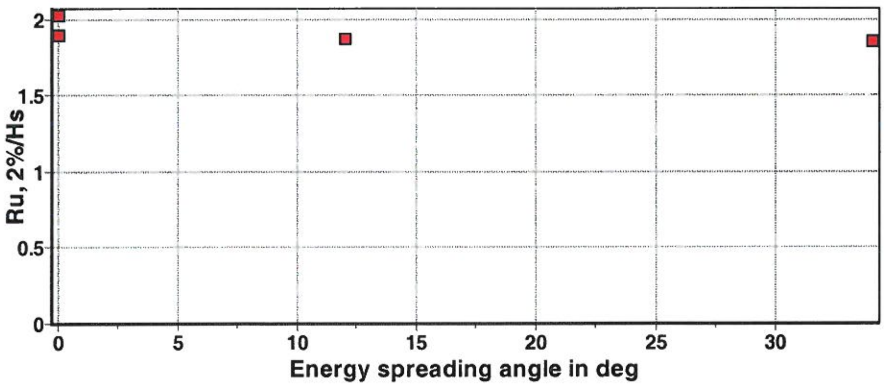


Figure 9. Run-up of head-on waves with various wave energy spreading angles.

Figure 10, showing $R_{u,2\%}/H_s$ of all the tests against mean wave incident angles, reveals that $R_{u,2\%}/H_s$ decreases with increasing wave incident angle.

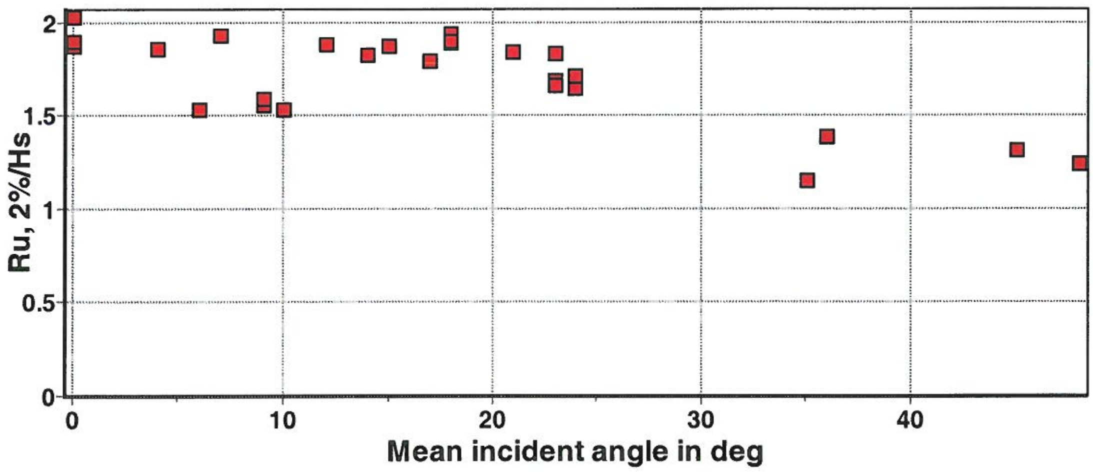


Figure 10. Wave run-up of all the tests.

The conclusion is consistent with the previous research by De Wall and van der Meer (1992).

7 Conclusions

- Wave run-up and run-down have been measured by a wave gauge and a step gauge. $R_{u,2\%}$ given by the step gauge is approximately 30% larger than that by the wave gauge, while $R_{d,2\%}$ given by the step gauge is approximately 30% smaller than that by the wave gauge.
- The influence of wave energy spreading angle on wave run-up is insignificant.
- Wave run-up is decreasing with increasing wave incident angle.

8 References

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